

Surveys

Inventory for Energy Production in Canada

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Abstract. Publicly available databases are analysed to demonstrate their relevance to life cycle inventory for energy production in the Canadian context. Site specific emissions along with sectoral emissions data are combined with production data to construct an energy production model, which has been applied to air emissions. The allocation procedure leads to reasonable results for coal, natural gas and electricity. The detailed allocation of the inventory among petroleum co-products is outside the scope of this study as it requires incorporating knowledge of physical relationship (unit process) or using economic data.

Keywords: Air emissions; coal; natural gas; electricity; energy production; LCI; life cycle inventory (LCI); petroleum products

Introduction

For any product system there is a need for ancillary energy data. From the acquisition of the raw material, fabrication, use and disposal or recycling of a product, energy data will be required to define the overall environmental profile. In Canada, on one hand there is no publicly available life cycle inventory (LCI) database on domestic energy production, but on the other hand, Statistics Canada, Environment Canada and Natural Resources Canada maintain high quality databases from which LCI for energy production can be calculated.

1 Definition of Goal and Scope

This section defines the specific decisions made in the construction of the life cycle inventory: criteria for database selection, function, functional unit, reference flow, system boundaries, description of data categories, impact assessment model, criteria for initial inclusion of data and data quality. Users should recognize that any LCA contains simplifications and assumptions.

The goal of this study is to demonstrate the methodology to develop LCI by type of energy use in Canada. With the life cycle perspective, quantification can be made for the activities upstream to ensure that the end user can make an informed decision.

The scope of the study is focussed on publicly available data, using 1997 as the base year. The sources of primary data are:

- from Statistic Canada: production data [1–4]
- from Environment Canada: the National Pollutant Release Inventory [5] (NPRI) for toxic substances as de-

fined by Canadian Environmental Protection Act (CEPA), the Canada's Greenhouses Gas Inventory [6] (CGGI), and the Criteria Air Contaminants Emission Inventories [7] (CAC)

- from Natural Resources Canada: an outlook on the Canada's greenhouses gases (CEO)[8].

The functional units are:

- the production of 1 tonne and 1 GJ of coal
- the production and distribution of 10^6 liters and 1 GJ of natural gas
- the production and distribution of 1 KWh and 1 GJ of electricity
- the production of 1000 liters and 1 GJ of refined petroleum products.

Coal mining and oil and gas extraction require the procurement of natural gas, petroleum products and electricity. Inventories related to those supplies are not considered by this LCI. The NPRI database gives inventories at facility level. It is a 'bottom-up'¹ compilation. Each facility can be retrieved under the Standard Industrial Classification (SIC) Codes. The other databases are 'top-down'. The CAC data are, for example, for industrial sectors such as 'Crude Oil Production'.

Three categories of data are compiled in this study: greenhouse gases (GHG), Criteria Air Contaminant (CAC) and CEPA toxic substances. The greenhouse gases emissions are aggregated using conversion factors accepted by the International Panel on Climate Change (IPCC). If carbon dioxide has a global warming potential of 1, methane has a potential of 21. The CAC are defined as total particulate matter (particulate), sulphur oxides (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC). The NPRI database compiles releases of toxic substances according to the CEPA.

Facilities are generally required to report to NPRI releases and transfers when their process stream is in excess of 10 tonnes per year. In the current study, the threshold for reporting is 95% by weight of the releases to the air.

The data quality has been estimated for various elements of the databases. The numbers in parentheses, in Table 1, are our estimations and the developers of the databases themselves have evaluated the others.

¹ Bottom-up and top-down are terms used to describe the level of detail within an inventory. Bottom-up is defined to include point sources and top-down refers to a sectoral level of detail.

Table 1: Uncertainties on the emissions from production

Database	Material flow	Sector	Uncertainty Percentage
Statistics Canada	Coal, natural gas, electricity, crude oil	Energy	(±5)
NPRI	All		(±10)
CGGI	CO ₂	Power generation Producer Consumption of energy	±5 ±20
	CH ₄	Upstream Oil and Gas Industry Fugitive Coal Mining	±30 +50/-30
CAC	SO _x	All sectors	±5 for 1990 data
	NO _x	Non transportation sector	Could not be determined
	CO	Non transportation sector	±30

The completeness is excellent for NPRI as reporting is compulsory. Representativeness is normally excellent. Data represent the integral Canadian situation with global coverage of technologies. As the CAC inventories are for the year 1990, uncertainty especially on SO_x can be underestimated as technological improvements are not considered. For all the other databases, the time coverage is 1997 as defined in the goal and scope.

2 Coal Production

The net supply for distribution, defined as the Canadian production less the producer consumption of coal is 78.54 Mt (or 1875 PJ). No significant emission is given in the NPRI. Emissions of particulates, SO_x, NO_x, VOC and CO are given in the CAC under COAL INDUSTRY. The CCGI estimates the methane fugitive emissions from this sector to be equivalent to 1.8 Mt CO₂ eq. Note that no emission is given under mining and under transportation. Table 2 presents emissions associated with the coal production in Canada, free on boards² (FOBs) the mine site.

² A condition of sale where the price of goods includes all charges until the goods are placed aboard the vessel (including a ship, railway car or other vehicle) in which they are to be shipped.

As Canada net exports represent 28% of its production, that environmental profile will be subsequently applied to other product systems.

3 Production and Distribution of Natural Gas

Natural gas and NGLs³ are co-products. The allocation of the different impacts is calculated based on the energy content. In 1997, the Canadian production of natural gas and NGLs were of 167.5 TL and 25.79 GL respectively. The producer consumption was 11.7 TL of natural gas and 0.139 GL of NGLs. The allocation of the emissions is based on their net production weighted by their respective energy content. On that basis, 1 GL of NGLs is equivalent to 606.3 GL of natural gas. The adjustment is in the order of 10%.

That section considers two large unit processes: the production of natural gas (and NGL's) and its distribution by pipeline. The inventories related to the operation of pipelines are assigned entirely to the distribution of natural gas. Table 3 presents the sources of emissions related to the unit processes.

³ Natural Gas Liquids. The hydrocarbons, ethane, propane, butanes, and pentanes plus or a combination thereof.

Table 2: Emissions related to the production of coal – FOBs the mine site

Emission		Production	
	t/y	g/t	g/GJ
CH ₄ expressed as CO ₂ eq.	1.80E+06	2.29E+04	9.51E+02
particulate	5.37E+04	6.83E+02	2.83E+01
SO _x	2.75E+03	3.51E+01	1.45E+00
NO _x	1.58E+03	2.01E+01	8.34E-01
VOC	3.37E+02	4.29E+00	1.78E-01
CO	5.90E+01	7.51E-01	3.12E-02

Table 3: Unit processes considered for the production and distribution of natural gas

Unit process	Database	Emissions
Production of natural gas and NGLs	CEO	Natural Gas Production 19.2 Mt CO ₂ eq. Natural Gas Processing 12.2 Mt CO ₂ eq.
	NPRI	Crude Petroleum and Natural Gas(specific natural gas) Natural Gas Liquids
	CAC	gas production including exploration and distribution
Distribution of natural gas and NGLs	CEO	Pipelines 17.5 Mt CO ₂ eq. Gas Distribution 3.5 CO ₂ eq.
	Statistics Canada	Energy to run pipelines: 6429 GL natural gas + 3430 GWh of electricity

Table 4: Emissions related to the production and distribution of natural gas

Emission	Production		Distribution		Total	
	t/y	t/y	t/y	t/y	g/ML	g/GJ
CO ₂ eq.	3.14E+07	2.18E+07	5.32E+07	3.10E+05	8.13E+03	
VOC	2.75E+05	1.03E+04	2.85E+05	1.66E+03	4.35E+01	
SO _x	2.48E+05	1.42E+04	2.62E+05	1.52E+03	4.00E+01	
NO _x	1.19E+05	6.21E+03	1.25E+05	7.30E+02	1.91E+01	
CO	2.36E+04	1.34E+03	2.50E+04	1.45E+02	3.81E+00	
Particulates	5.86E+02	1.12E+03	1.71E+03	9.95E+00	2.61E-01	
Carbon disulphide	3.03E+03	1.14E+02	3.15E+03	1.83E+01	4.81E-01	
Toluene	1.24E+02	4.63E+00	1.28E+02	7.47E-01	1.96E-02	
Benzene	1.13E+02	4.23E+00	1.17E+02	6.82E-01	1.79E-02	
Xylene (mixed isomers)	1.03E+02	3.85E+00	1.07E+02	6.21E-01	1.63E-02	
Sulphuric acid	6.89E+01	3.32E+01	1.02E+02	5.94E-01	1.56E-02	
Ethylene glycol	4.42E+01	1.66E+00	4.59E+01	2.67E-01	7.01E-03	

Table 4 presents emissions according to the unit process defined in Table 3.

4 Production and Distribution of Electrical Power

The total production of electricity was of 556.9 TWh in 1997. Canada was a net exporter of electricity of 6.4% of its production or 35.7 TWh. As hydroelectricity is considered emission free and as electricity exports are from provinces rich in that resources, all those exports are considered to be emission free. The global Canadian production is at 62% from hydro, 14% from nuclear and 16% from coal. Oil and gas represent 7% of the source of energy. No emission is considered associated with nuclear electricity. As the losses and own use by the producers total 40.8 TWh, the net domestic demand is 480.4 TWh.

Site specific emissions are from NPRI using American SIC 4911, ELECTRIC SERVICES. Criteria Air Contaminants for the SECTOR ELECTRIC POWER GENERATION is used. From COE, the direct emissions of GHG are estimated to 111 Mt.

Utilities burned 49.5 Mt of coal and 3.736 TL of natural gas. Table 5 presents emissions associated with the production of electricity for different unit processes and presents more than 95% of the NPRI emissions along with the GRH gases and the CAC emissions.

For the electricity production, the only significant emission from the acquisition of the natural gas is associated with the VOC.

5 Production of Refined Petroleum Products

The production of refined petroleum products is complex. Canada produces crude oil from various types: heavy, light and medium, synthetic, crude bitumen. Canada is a net exporter of crude oil. The analysis of the system has been simplified by applying the inventory related to the production of conventional oil and non-conventional oil to the total crude oil production. The GRH emissions for the production of crude oil are estimated to 44.7 Mt CO₂ eq. The inventory related to the refinery is applied to the industrial Canadian demand. The total production of crude oil was of 123.7 GL. Canada imported 44.2 GL and exported 70.7 GL. The

Table 5: Emissions related to the production of electricity

Emission	Coal Production	Natural Gas Production and Distribution	Electricity Production Direct Emissions	Total Emissions		
				t/y	g/kWh	g/GJ
CO ₂ eq.	1.14E+03	3.00E+04	1.11E+08	1.11E+08	2.31E+02	6.42E+04
SO _x	1.74E+00	1.48E+02	6.90E+05	6.90E+05	1.44E+00	3.99E+02
NO _x	9.96E-01	7.07E+01	2.45E+05	2.45E+05	5.11E-01	1.42E+02
particulates	3.39E+01	8.03E+01	1.54E+05	1.54E+05	3.21E-01	8.92E+01
CO	3.72E-02	1.41E+01	6.44E+04	6.44E+04	1.34E-01	3.72E+01
VOC	2.13E-01	1.61E+02	2.01E+03	2.17E+03	4.19E-03	1.16E+00
Hydrochloric acid		2.56E-02	6.34E+03	6.34E+03	1.32E-02	3.67E+00
Sulphuric acid		5.76E-02	4.29E+03	4.29E+03	8.93E-03	2.48E+00
Hydrogen fluoride		5.42E-03	1.34E+03	1.34E+03	2.80E-03	7.77E-01

Table 6: Emissions related to the production of petroleum products

Emission	Crude Oil Production	Petroleum Refinery	Total		
			t/y	t/y	g/kL
CO ₂ eq.	4.47E+07	1.86E+07	6.33E+07	3.08E+05	7.89E+03
SO _x	2.15E+05	9.50E+04	3.10E+05	2.78E+03	7.13E+01
VOC	2.04E+04	6.66E+04	8.70E+04	8.71E+02	2.24E+01
NO _x	2.04E+04	2.64E+04	4.68E+04	4.47E+02	1.15E+01
CO	1.10E+04	1.36E+04	2.46E+04	2.35E+02	6.03E+00
particulates	4.18E+03	5.23E+03	9.41E+03	8.97E+01	2.30E+00
Ammonia (Total)	1.46E+03	1.25E+02	1.59E+03	1.34E+01	3.44E-01
Xylene (mixed isomers)	7.14E+02	5.33E+02	1.25E+03	1.15E+01	2.96E-01
Sulphuric acid	1.10E+03	2.99E+00	1.10E+03	9.06E+00	2.33E-01
m-Xylene		6.65E+02	6.65E+02	7.02E+00	1.80E-01
Propylene	1.30E+02	4.19E+02	5.49E+02	5.49E+00	1.41E-01
Toluene	5.86E+02		5.86E+02	4.84E+00	1.24E-01
Cyclohexane	3.85E+02	1.57E+02	5.42E+02	4.83E+00	1.24E-01
Ethylene	6.54E+01	3.51E+02	4.16E+02	4.25E+00	1.09E-01
Benzene	1.18E+02	3.07E+02	4.25E+02	4.21E+00	1.08E-01
1,2,4-Trimethylbenzene	3.04E+02	9.82E+01	4.02E+02	3.54E+00	9.09E-02
Carbon disulphide	3.11E+02		3.11E+02	2.56E+00	6.57E-02
Ethylbenzene	1.64E+02	1.07E+02	2.71E+02	2.48E+00	6.36E-02
Methyl tert-butyl ether		1.49E+02	1.49E+02	1.58E+00	4.05E-02
Methyl ethyl ketone		1.24E+02	1.24E+02	1.31E+00	3.35E-02

producer consumption is estimated to be 2.437 GL. Table 6 presents the emissions associated with the petroleum products according to the production stage.

The emissions have been assigned equally to the large quantity of refined products based on an average density and energy content. Refined petroleum products comprise numerous co-products such as gasoline, diesel, bunker and naphtha. Refinement of the allocation among co-products requires the use of physical relationship (unit process) or economic data.

6 Conclusions

Methodology for the elaboration of LCI has been demonstrated for the energy sector in Canada using publicly available databases. Sectoral production data have been combined with site specific and source sector emission data in order to construct a life cycle inventory for gaseous emissions comprising, 95% by weight of the airborne CEPA toxicants, related to the energy production. The allocation procedure is reasonable for coal, natural gas and electricity. The allocation of the inventory among petroleum co-products is outside the scope of this study, as it requires incorporating extended knowledge of physical relationship (unit process) or using economic data.

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